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Service Testing of the Resco Steered Frame Freight Car Truck on the Norfolk Southern Railway, and Comparisons with Standard and Premium Three-Piece Trucks

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By
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Since some of the accepted measures in the railway industry are imperial, metric measures are not always used in this report.

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16. Abstract

This report describes tests of the Resco Steered-Frame Truck conducted on the Norfolk Southern Railway. The tests involved operating the prototype trucks in revenue service between a coal mine and a power station, but the data reported was recorded at a specific location in Loudon, TN. Data from other revenue cars passing the same test station were used for comparison. The trucks had been modified to incorporate improvements that had been identified as necessary in previous testing at Pueblo, CO.

The tests have shown that the Resco truck outperforms the standard three-piece truck as well as other premium trucks by a significant margin. A peripheral result from the tests was that it became clear from the data that three-piece trucks frequently operate in a "warped" condition, and that the premium trucks have no self-steering capability – they do remain "square" however, unlike the standard three-piece truck. The Resco truck was shown to steer nearly perfectly, despite the fact that there was some interference between the truck and some brake brackets on the car frame, and that the rail profiles through the test section of the track were highly unsuitable for use with the new AAR1B wheel profiles that the trucks were fitted with. The standard and premium truck data was taken with service worn wheels.

Some design deficiencies have been identified, primarily in the realm of clearances to the body-mounted brake linkage. These need to be addressed in the production design. It is felt that the steered-frame truck is now ready to move to a production design and to enter the AAR approval process.

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16. Résumé

Ce rapport décrit les essais du bogie de wagon de marchandises orientable de Resco, réalisés sur une ligne du Norfolk Southern Railway. Des prototypes du bogie ont été installés sur des wagons en service payant qui faisaient la navette entre une mine de charbon et une centrale électrique. Toutefois, les données dont fait état le rapport ont été enregistrées à un point précis du trajet, situé à Loudon, TN. Les données d'autres wagons en service payant qui passaient par le même poste d'essai ont été recueillies à des fins de comparaisons. Les bogies avaient été modifiés pour recevoir les perfectionnements reconnus nécessaires lors d'essais antérieurs menés à Pueblo, CO.

Les essais ont révélé que le bogie de Resco surclasse, et de loin, le bogie à trois éléments standard, de même que d'autres bogies de catégorie supérieure (dits *premium*). Un résultat accessoire de ces essais est qu'ils ont clairement montré que les bogies à trois éléments sont souvent «gauchis», et que les bogies de catégorie supérieure ne sont aucunement auto-directeurs – ils demeurent toutefois «carrés», contrairement au bogie à trois éléments standard. Le bogie Resco s'orientait presque parfaitement, malgré une interférence entre le bogie et certains supports de freins fixés au châssis du wagon, et malgré que les profils de rail du tronçon d'essai ne convenaient pas du tout aux nouveaux profils de roue AAR1B qui équipaient les bogies. Les données concernant le bogie standard et le bogie de catégorie supérieure ont été colligées avec des roues qui s'étaient usées naturellement en service.

Certaines lacunes de conception ont été décelées, notamment en ce qui a trait aux dégagements par rapport à la timonerie de frein montée sur la caisse. Ces lacunes devront être corrigées à l'étape du modèle de production. Tout indique que le bogie orientable est maintenant prêt à passer à l'étape du modèle de production et à être inscrit au processus d'approbation de l'AAR.

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Project Team

Resco Engineering
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Executive Summary

Over-the-road tests were conducted on a pair of Resco Engineering Steered-Frame freight car trucks. Previous testing at the AAR test centre in Pueblo, CO, had shown that these trucks have higher levels of performance than other freight car trucks designed for the heavy axle load environment typical of North America. The Norfolk Southern Corporation (Norfolk Southern Railway) has expressed an interest in utilizing this technology on coal cars and wished to demonstrate the steering performance in operation on an actual railroad.

Some design issues on the trucks that were identified in previous testing were corrected and the trucks were then submitted to Norfolk Southern for testing. Tests were conducted over a section of track at Loudon, TN, where the railroad has an instrumented rail setup installed on a pair of back-to-back curves.

A number of difficulties arose with installation under the cars in the railroad shops. Some of these difficulties were due to design features of the truck that will need attention in the production design phase. Examples of these include allowing for the location of floor jacks that lift the car and allowing for the full motions of the brake live levers. Other practical difficulties included the unavailability of suitable length brake connectors at the Knoxville car shop (causing delay while these were obtained), the requirement to shim the springs in order to achieve correct coupler height (even though another car with the same nominal centreplate height had not required shimming), and an incident in which the loaded car was dropped from the jacks, damaging one of the trucks. Once these difficulties were overcome and the trucks were installed under the required car, the car was operated in revenue service and measurements of the truck performance were made.

Sufficient data was available from running the steered trucks, premium (M976) three-piece trucks, and standard three-piece trucks through the test site that statistical analysis was possible for all three types. The results highlighted two valuable pieces of information – premium trucks behave as rigid frame trucks (with little or no self-steering action), and the Resco Steered Frame Truck exhibits near-perfect steering behaviour even under fairly extreme adverse conditions.

Following the operation of the steered trucks through the Loudon test site, they re-entered the revenue service stream and continued to the load dumping location; from there they were to return to the mine for a further loading cycle. On the empty return trip, however, the car was unattended and, despite a DO NOT HUMP order, was inadvertently run through a humping operation near Roanoke, VA. The prototype trucks had not been designed to withstand the forces exerted by the retarder in a hump yard and, as a result, an axle was torn off one of the steered trucks. This caused further damage to the truck and brought the test to an end. Nearly all of the required data from the test had been gathered at this point – the continued operation would not have seen repeated passes through the wayside monitoring station at Loudon, only one pass per cycle – so very little data was lost by this event.

When the trucks were removed from the car and taken to the Norfolk Southern laboratory for examination, a very important factor became evident that had not been noticed before. It was clear that the dead lever bracket for the body-mounted brake system on the car sill had been interfering with the truck shear frame. There was very severe distortion and wear of the cross beam of that frame. This interference had not been identified when the truck was installed and the brake linkage was connected because the car had been in the empty condition at that time, as well as being on tangent track. The result of this interference was that one truck would have experienced severe resistance to rotating properly on one curve in the test site and the other would have suffered the same problem in the other curve. It was clear, from the damage to the cross beam, that very large forces were created to generate the required rotation – which explains the lateral wheelset forces being higher than anticipated.

Rail profiles were taken at the test site and these were examined after the test. It was found that the profiles were such that severe anti-steering moments would have been produced at all of the axles of the steered trucks (with new AAR1B wheel profiles). Contact between wheel and rail was close to the middle of the tread for both the high and the low wheels – meaning that the required rolling radius difference between inner and outer wheels could not be generated. Once the wheels have been in service for some time they generate a greater depth to the throat of the profile and thus it is possible for proper rolling radius differences to be generated, even with the rails ground in the manner that they were. It is probable, therefore, that many of the M976 and standard three-piece trucks whose data are shown here had wheel/rail contacts that generated a correct steering moment – or, at the very least, suffered less anti-steering moments than did the steered trucks.

To summarize the results from this test program – the Resco Steered-Frame Truck has demonstrated that, even with severely negative operating conditions, it has a steering performance that far exceeds that of the premium M976 trucks or the standard three-piece truck. It can be anticipated that the performance will be significantly better than shown here once the physical interference issues have been designed around (a process that is already under way) and when they are operating in an environment that produces more desirable wheel/rail contact conditions. That said, the performance demonstrated herein is, nevertheless, very attractive and substantially better than that of the currently available premium trucks. A subsidiary result from the program is that it has been shown quite clearly that the currently available premium freight car trucks have no significant self-steering capability – their benefit relative to the standard three-piece truck is that they prevent the warp (or shear) collapse that plagues those designs and contributes to their worst performance. Interestingly, however, the worst of the M976 trucks is only slightly better than the worst of the standard 3-piece trucks – whereas the worst of the steered trucks is substantially better than the worst of either of the other two.

The Resco Steered-Frame Truck, in prototype form, has now fully demonstrated its potential as a freight car truck for North America, and for other heavy haul applications. Further testing of the prototype trucks, especially considering the damage they sustained during this round of testing, would not provide significant further value. The next step is

to create a production design, incorporating everything that has been learned in the prototype testing, and to embark upon a program to gain AAR approval. Resco Engineering is actively seeking a partner with whom to embark on this effort.

Sommaire

Des essais en service ont été réalisés sur une paire de bogies de wagon de marchandises orientables de Resco Engineering, désignés *Steered-Frame*. Des essais antérieurs menés au centre d'essai de l'AAR à Pueblo, CO, avaient montré que ces bogies offrent des niveaux de performance supérieurs à ceux d'autres bogies de wagon de marchandises conçus pour les lourdes charges aux essieux qui caractérisent le contexte d'exploitation nord-américain. La Norfolk Southern Corporation (Norfolk Southern Railway) s'était dite intéressée à utiliser cette technologie dans ses wagons à charbon et souhaitait participer à la démonstration des performances du nouveau bogie sur une voie ferrée réelle.

Des lacunes de conception, qui avaient été décelées au cours d'essais antérieurs, ont été corrigées, puis les bogies ont été livrés au Norfolk Southern pour les essais. Ceux-ci ont eu lieu sur un tronçon de voie à Loudon, TN, là où le chemin de fer possède un montage de rails instrumentés installé sur une paire de courbes dos-à-dos.

Un certain nombre de difficultés ont marqué l'installation des bogies sous les wagons, dans les ateliers ferroviaires. Certaines de ces difficultés étaient dues aux caractéristiques de conception du bogie, lesquelles devront être corrigées à l'étape du modèle de production. Par exemple, il faudra prévoir des points d'appui pour les crics rouleurs qui lèvent le wagon, ainsi que les dégagements nécessaires pour permettre les mouvements des balanciers de freins. De plus, des difficultés d'ordre pratique se sont présentées. En effet, l'atelier de Knoxville ne disposait pas de raccords de frein de la bonne longueur (d'où un retard dû au délai de livraison). Et il a fallu ajouter une cale d'épaisseur aux ressorts pour que l'attelage soit à la bonne hauteur (à noter qu'un autre wagon présentant une plaque centrale de même hauteur nominale n'avait pas eu besoin d'une cale d'épaisseur). Enfin, il est survenu un incident au cours duquel le wagon chargé est tombé des crics, ce qui a endommagé un des bogies. Une fois ces difficultés surmontées et les bogies installés sous le wagon voulu, celui-ci a été mis en exploitation en service payant et les performances des bogies ont été mesurées.

Les données recueillies au site d'essai concernant le fonctionnement en service des bogies orientables, des bogies à trois éléments de catégorie supérieure (M976) et des bogies à trois éléments standard, ont été suffisantes pour que l'on puisse faire une analyse statistique des trois types de bogies. Les résultats ont débouché sur deux éléments d'information précieux : les bogies de catégorie supérieure se comportent comme des bogies à châssis rigide (ils sont très peu, voire aucunement auto-directeurs) et le bogie orientable de Resco affiche un comportement auto-directeur presque parfait, même dans des conditions extrêmement défavorables.

Après être passés par le site d'essai de Loudon, les bogies orientables retournaient à une exploitation en service payant. Ils poursuivaient leur route jusqu'au lieu de déchargement et de là, ils étaient ramenés à la mine pour un nouveau chargement. Mais pendant le trajet de retour à vide, le wagon n'était pas surveillé et, malgré un placard portant la mention *DO NOT HUMP* (*Éviter les bosses*), il a traversé par inadvertance un triage à bosse près de Roanoke, VA. Or, les prototypes n'avaient pas été conçus pour résister aux forces

exercées par les freins de voie dans un triage à bosse et, par conséquent, un essieu s'est détaché d'un des bogies orientables. Cela a occasionné d'autres dommages au bogie et l'essai a dû être interrompu prématurément. Mais presque toutes les données nécessaires avaient alors été colligées – le reste de l'essai ne prévoyait pas de mesures répétées au poste d'essai de Loudon (un seul passage par cycle était prévu) – l'incident n'a donc privé les chercheurs que de très peu de données.

Lorsque les bogies ont été retirés du wagon et apportés au laboratoire du Norfolk Southern pour examen, une constatation très importante a été faite, qui n'avait jamais été faite auparavant. En effet, il est apparu clairement que le support de balancier passif de la timonerie de frein, montée sur le longeron du wagon, avait fait obstruction au cadre de cisaillement du bogie. Une déformation et une usure très importantes de la membrure transversale de ce cadre ont été constatées. Cette interférence n'avait pas été notée au moment de l'installation du bogie et du raccordement de la timonerie de frein, parce que le wagon était vide et qu'il était sur une voie rectiligne. Or, à cause de cette interférence, un des bogies aurait été le siège d'une forte résistance à la rotation dans une des courbes du site d'essai, et le même problème se serait présenté dans l'autre courbe. Il est clairement ressorti, d'après les dommages subis par la membrure transversale, que de très grandes forces étaient générées pour produire la rotation voulue – ce qui explique que les efforts transversaux exercés sur les essieux montés étaient plus importants que prévu.

Les profils de rail ont été pris sur le site d'essai et ont été examinés après l'essai. Il a alors été constaté que ces profils étaient tels que de grands efforts anti-rotation avaient dû être générés dans tous les essieux des bogies orientables (dotés des nouveaux profils de roue AAR1B). Le contact entre la roue et le rail se faisait près du milieu de la surface de roulement, tant pour les roues extérieures que pour les roues intérieures – ce qui signifie que l'écart nécessaire entre le rayon de roulement des roues intérieures et celui des roues extérieures n'a pas pu être obtenu. Après que les roues ont été en service pendant un certain temps, le congé du profil de roue s'approfondit. Il est donc possible d'obtenir les écarts voulus entre les rayons de roulement, même avec des rails présentant le profil de ceux du site d'essai. Il est donc probable que beaucoup des bogies à trois éléments M976 et standard, dont les données sont reproduites dans ce rapport, avaient des interactions roue/rail qui généraient des efforts de rotation corrects – ou, à tout le moins, subissaient moins les effets d'efforts anti-rotation que les bogies orientables.

Pour résumer les résultats de ce programme d'essai, le bogie orientable de Resco a montré, même dans des conditions d'exploitation très défavorables, une performance, sur le plan de l'orientation, de beaucoup supérieure à celle des bogies M976 de catégorie supérieure, dits *premium*, ou du bogie à trois éléments standard. On peut penser que cette performance sera beaucoup meilleure que celle rapportée ici lorsque les problèmes d'interférence physique auront été résolus (le travail en ce sens est déjà en cours) et lorsque les bogies seront exploités dans un environnement propice à un meilleur contact roue/rail. Cela dit, la performance enregistrée au cours des présents essais est néanmoins très intéressante et surpasse de beaucoup celle des bogies de type *premium* actuellement utilisés. Le programme a aussi eu comme résultat accessoire de montrer assez clairement que les bogies de wagon de marchandises de catégorie supérieure présentement utilisés

ne sont pas vraiment auto-directeurs – leur avantage par rapport au bogie à trois éléments standard est qu'ils préviennent la déformation par gauchissement (ou cisaillement), qui est le fléau de ces modèles de bogie et qui contribue à leur piètre performance. Fait intéressant, toutefois, le pire des bogies M976 n'est que légèrement supérieur au pire des bogies à trois éléments standard – tandis que le pire des bogies orientables surclasse amplement les pires des deux autres types de bogies.

Le bogie orientable de Resco, dans sa version prototype, a maintenant démontré tout son potentiel en tant que bogie de wagon de marchandises bien adapté au contexte de l'Amérique du Nord, ainsi qu'à d'autres applications de transport lourd. D'autres essais des prototypes ajouteraient peu à ce que l'on sait déjà, surtout si on songe aux dommages qu'ils ont subis au cours de la présente campagne d'essai. La prochaine étape consistera à créer un modèle de production qui incorporera tout ce qui a été appris lors des essais de prototype, et d'entreprendre un programme pour obtenir l'approbation de l'AAR. Resco Engineering est à la recherche d'un partenaire pour se lancer dans un tel programme.

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1. Background

The Resco Engineering Steered Frame Freight Car Truck is a concept that provides direct steering of the axles of a freight car, in a package that is at the same time simple, inexpensive, and lightweight.

Initial rollout tests were conducted, on a pair of prototype trucks, on BC Rail's tracks at Lillooet, British Columbia. This work was reported in Transport Canada report TP 13334E.

Comprehensive testing, comparing the performance of the trucks against that of standard three-piece trucks and premium three-piece trucks, was conducted at the AAR's facilities in Pueblo, CO. The results were recorded in Transport Canada report TP 14075E. Certain design deficiencies were identified during those tests but the performance achieved by the RESCO truck nevertheless exceeded that of all the other trucks tested, in every category of test.

Subsequently to the reporting of the results from the AAR tests The Norfolk Southern Railroad offered to conduct running tests of the prototype hardware in its coal operations. The test results achieved in the previous testing, showing very much reduced lateral forces and rolling resistance, coupled with lower mass than a conventional truck, were the principal factors that inspired the interest in this device at Norfolk-Southern.

The program of work reported herein consisted of designing and implementing modifications to the trucks to address the issues identified in the earlier program and then to test the trucks under coal cars on the Norfolk Southern network.

2. Design Changes

The principal areas where change was required was in the way in which the hydraulic damper links were angled, in order to provide adequate lateral damping, and in the retention of rollers between the vertical suspension springs and the car body bearing plates. Two previous designs of roller assembly had been tried but there remained problems in retaining the rollers in place over a long period of operation.

2.1 Damper orientation

Figure 1 shows the two alternative orientations that could be used in order to create the desired effect where the rotary damper units produce damping forces in both the lateral and the vertical directions. The first alternative (the one initially installed) provides the required vertical and lateral effects but has the drawback that it has little damping effect for Lower Centre Roll motions – those that take place primarily in roll about a centre that is below the CG of the car (and typically at or below the top of the rail). The Pueblo testing showed that the damping in this mode was inadequate. The second alternative – where the dampers are, in effect, transposed to opposite sides of the car – creates much more damping in the Lower Centre Roll mode. For the series of tests at Norfolk

Southern the dampers were placed in this second orientation. This necessitated some modification to the brackets on the truck frame connecting the lower ends of the damper links to the frame.

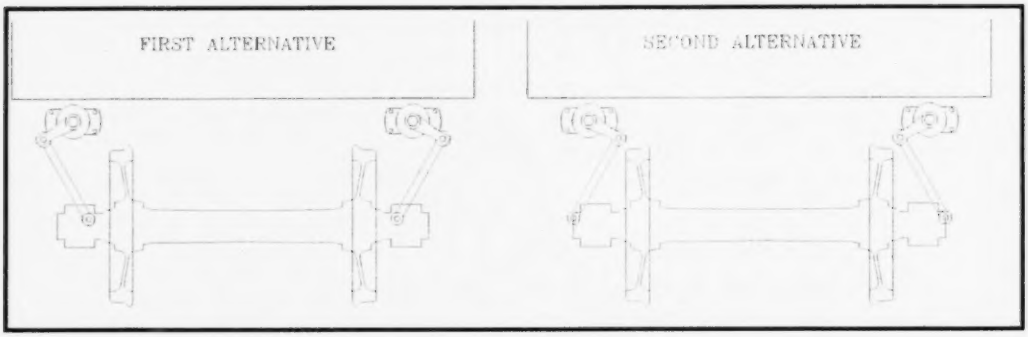

Figure 1. Alternative Damper Orientations

2.2 Roller Modifications

Figure 2 shows the arrangement of rollers designed and manufactured for these tests.

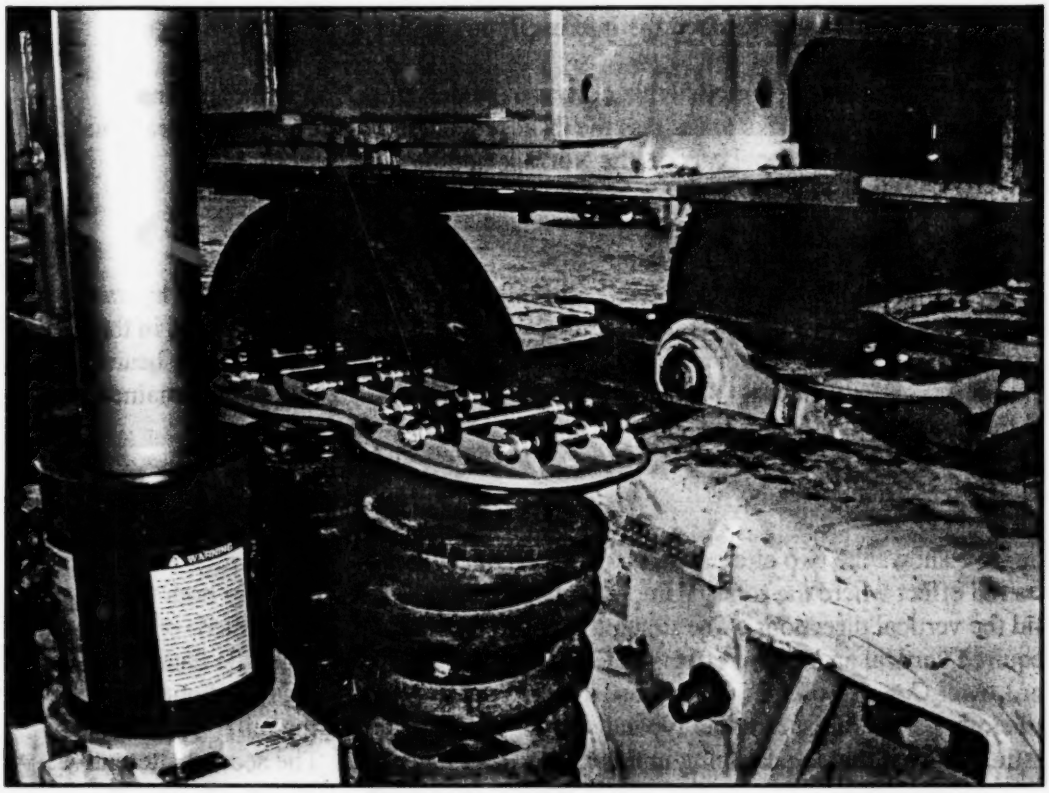

Figure 2. Spring Rollers

A set of steel castings was manufactured. These castings span across the tops of the outer springs of the truck – one casting on each side of the truck. Each casting has a series of longitudinal ribs formed in its upper surface and semi-circular notches are machined into those ribs. Two rollers are mounted on each of a set of axles that rest in the semi-circular notches; the rollers being captive between adjacent ribs when installed. A hardened steel plate, angled to match the inclination of the springs, is mounted on the underside of the car. This arrangement keeps the rollers captive with the springs and thus they cannot 'migrate' as had been the case with previous designs.

2.3 Carbody Interface

The bodies of the cars that Norfolk Southern proposed to use for these tests had geometric differences from the aluminum gondolas used at Pueblo. In order to match the trucks to the carbodies some modifications were necessary to the adapters that accommodate the trucks to the cars. When Norfolk Southern later changed the test car from a gondola to a bottom dump car that necessitated some further modifications to the adapters.

3. Test Location

The cars were initially to be operated over a section of track near Loudon, TN, where Norfolk Southern had installed a set of instrumentation to measure wheel/rail forces, axle angles-of-attack, and axle lateral position. Multiple runs were recorded in both directions over the test area.

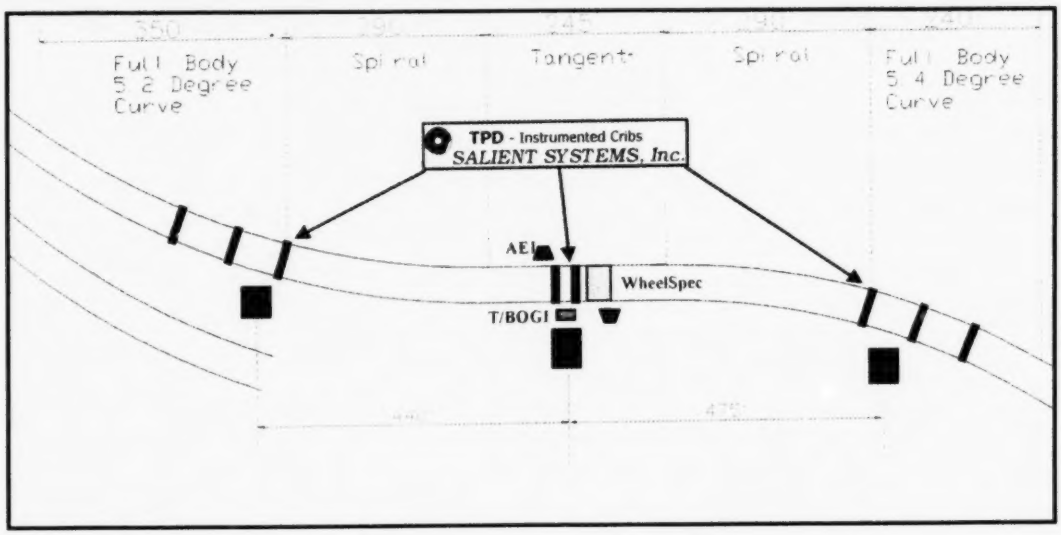

Figure 3. Loudon Test Site

The section of track at Loudon that comprises the test section has a number of measurement devices installed in it. There are two back-to-back curves, of

approximately 5° of curvature (~1100 ft radius), connected by a length of tangent track. Instrumentation is installed at the end of each constant radius curve section, and at the centre of the tangent. In all three locations there are strain gauge installations. Three sets of strain gauges from Salient Systems Inc., at each of the three locations, are installed on the web of the rail, and these are calibrated to provide information on the lateral and vertical forces acting on the rail. A T/BOGI system and a Wheelspec system are also installed at the tangent section. A diagram of the test site is shown in Figure 3.

In subsequent tests the cars were operated in revenue service over a complete loop from the Roanoke shops (where the trucks were installed) to the mine (empty) and then to the power utility for unloading. In the process of this operation the test car passed by the Loudon test site, where it was cut out of the train and formed into a consist with a number of other cars and operated repeatedly through the test site. The test car was then released back into service to continue to the dumper.

Figure 4 shows the test consist on the track at Loudon. A Norfolk-Southern caboose is used as an instrument car. It contains rack mounted instruments, video recording equipment, etc. In this case there was no instrumentation on the truck – all measurements were made from the wayside so the caboose was used only for the video recording equipment, which showed the truck steering mechanism in operation, and to house the test crew. The car next to the caboose is the one carried on the RESCO trucks so it was possible to monitor the behaviour of the truck nearest to the caboose visually – as well as with the video equipment.

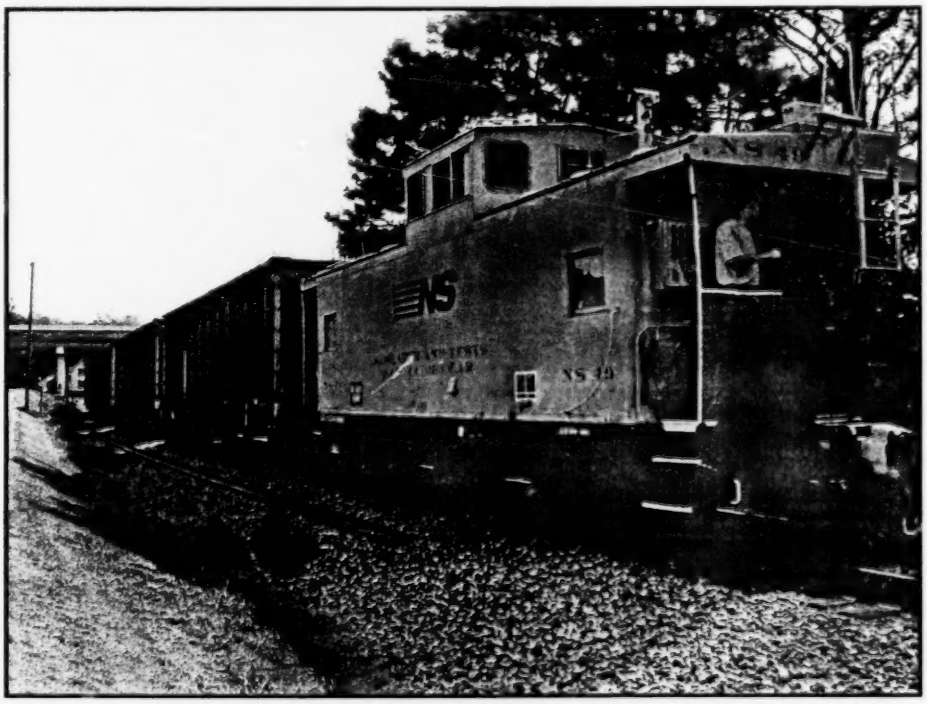

Figure 4. Test Consist

4. Installation Difficulties

A first attempt to install the trucks under the loaded test car at Knoxville, TN, was successful but it was found, once the installation was complete, that the coupler height on the Norfolk-Southern car was lower than is allowed under AAR rules. No explanation for this could be found – the height under the loaded gondola at Pueblo had been within the prescribed limits. The trucks were removed from the car while a set of spacers was manufactured – to be placed on top of the springs in order to bring the height to the required limit.

It was also found that the brake rods used on the original truck were too short for use in the Resco truck and that longer rods were not available in Knoxville to suit the condition so the delay was used to get some suitable rods to the site as well.

The installed truck is shown in Figure 5.

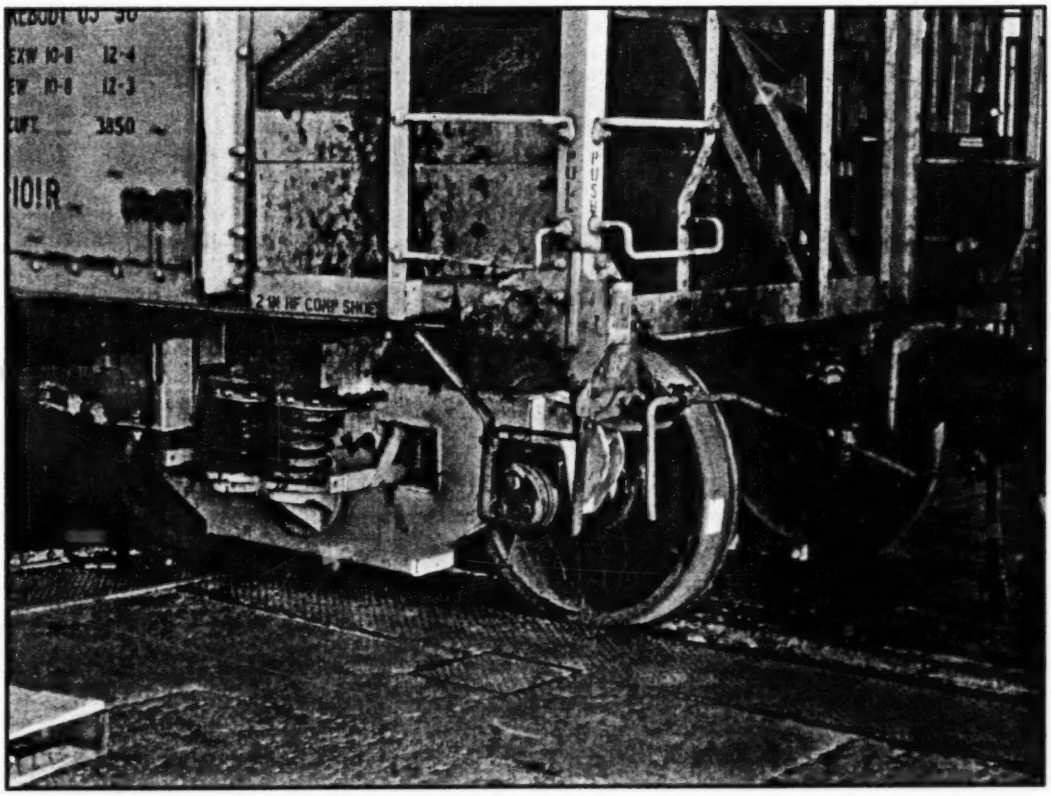

Figure 5. Truck Installation

The spacers were manufactured, and suitable length brake rods were obtained. The spring spacers are shown in Figure 6. Another visit was made to Knoxville and an attempt was made to re-install the trucks under the car.

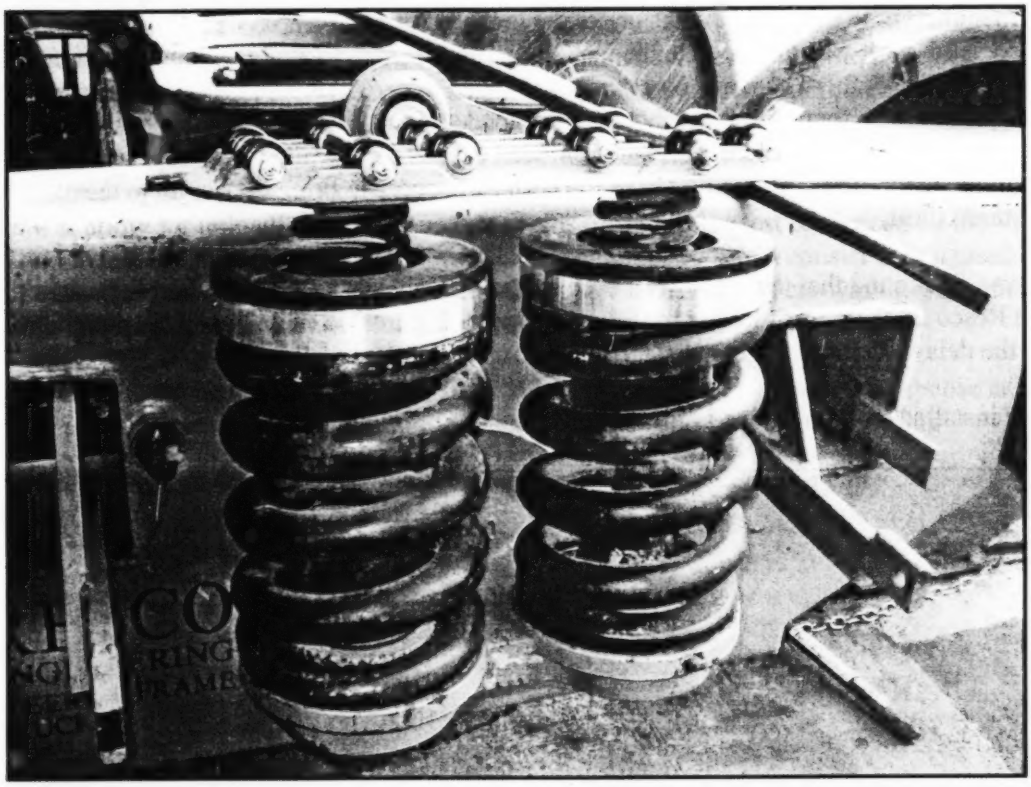

Figure 6. Spring Spacers

The first truck was installed without incident. During installation of the second truck, however, a problem occurred with the jacking of the car. The jacks were inadvertently placed on a section of the floor having cover plates over an access hatch. When the car was lifted, the jacks began to tilt sideways because of the uneven strength of the floor. This situation is illustrated in Figure 7.

Unfortunately, by the time this condition had become evident to the team observing the lift it was too late to put the car back down – the lateral shift of the car was such that it would no longer re-engage with the truck. Several measures were attempted to straighten the jacks and thus be able to lower the car and then jack in a more suitable location. Unfortunately, during one of these attempts, the jacks slipped out from under the car and the loaded car fell onto the truck at that end. Some damage was done to certain of the truck components – the traction beam that spans across the inner springs and contains the hole to engage with the body centreplate was bent, as was one of the roller castings from the top of the outer springs on one side. The carbody adaptor was also bent. Slight nicks

were made in the top of the sideframe, where the main mass of the car came to rest, but no serious damage was caused to those members.

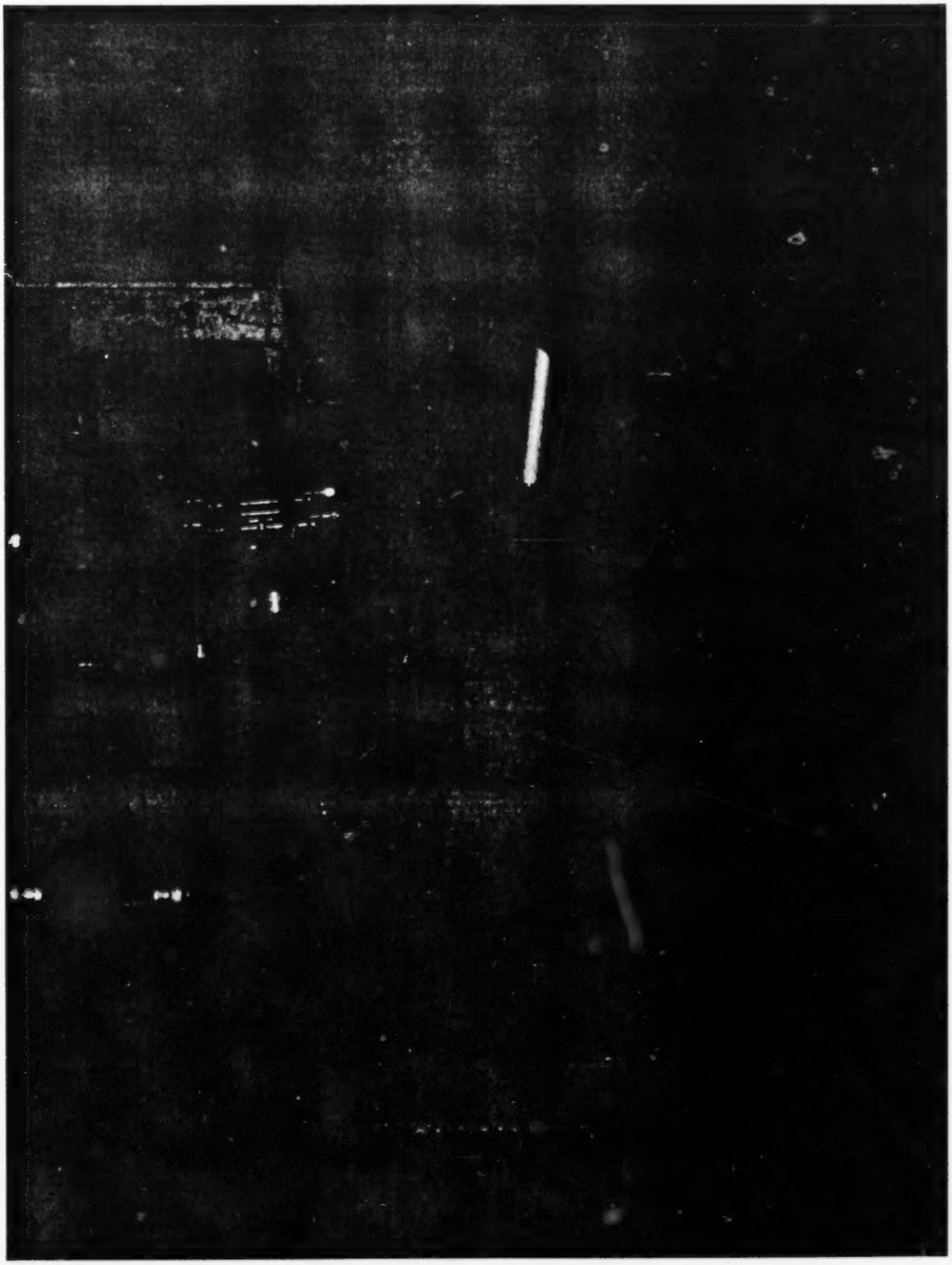

Figure 7. Jack Inclination

The damage, though reasonably slight, considering the weight of the car that had fallen, was sufficient to prevent the test from continuing with that truck. It was decided to continue with the test plan but with only one truck under the car being of the steered type.

5. Initial Tests

The results from the tests with only one truck were considered to be disappointing. From examination of the video transmissions of the truck motions during curving it was clear that full steering motions within the truck were not taking place. The results from the wayside detectors also showed that the lateral forces in the wheelsets were higher than anticipated. Close examination of the Resco truck revealed a condition that had not been identified previously. The rollers that had been applied to the top of the suspension springs were found to have moved off the edge of the body plate and were trapped against its edge. The roller condition is shown in Figure 8.

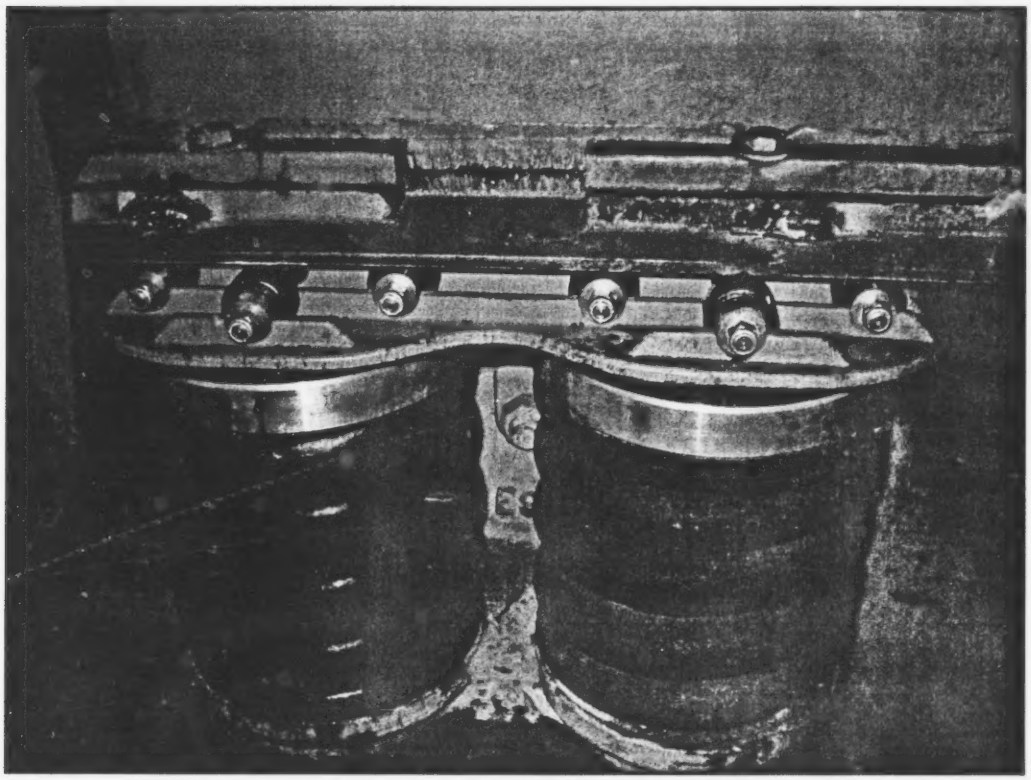

Figure 8. Roller Offset Condition

This would provide substantial resistance to the truck rotation – thus explaining why the steering motions were inhibited and why the lateral forces were higher than expected.

It was also found that another pair of trucks being tested in parallel with the Resco truck, in the same consist, had a deficiency which invalidated their test results.

A further complication that was identified when the test site was examined carefully was that the rail through the test site had been ground to profiles that are inappropriate for such curves. The high rail had contact in the field-centre area of the head, whereas the low rail had contact on the gauge-centre area of the head. The preferred contact conditions in a curve are for the high rail to be contacted close to the gauge corner and the low rail to be contacted towards the field side of the centreline. This condition creates a steering moment on the wheelset, and a rotational moment on the truck, which encourages centring of the wheelset and minimizes lateral forces. The condition which existed at the rail head tends to create the opposite effect – it produces anti-steering moments and high lateral forces.

It was decided to abort the test and make another attempt at testing the Resco trucks once the necessary repairs had been made to the damaged truck. The Norfolk Southern representative present also committed to having the rail condition corrected at the test location.

6. Second Test

Once the damaged parts had been repaired and/or replaced, another attempt was made to complete the testing of the Resco trucks. Norfolk Southern determined that they no longer wished to jack the cars in the loaded condition to assemble the trucks, even in a location that had no floor deficiencies. This being the case, the car type under which the trucks were to be tested had to be changed.

The original cars that the Resco trucks were fitted to were gondolas – suited for use in a rotary dumper. Because the Resco prototype trucks had not been designed with rotary dump in mind it was felt to be unwise to subject them to that operation. The test plan called for the trucks to be installed under the loaded car, operated through the test area a number of times, and then the trucks removed and the car taken to the dumper with standard trucks.

Once it was decided that jacking the loaded cars was not an option the car type had to be changed to a bottom-dump type because the Resco truck could be taken through that type of unloading cycle without risk. The test program would then consist of operating the truck in the empty condition from the assembly location to the coal mine, then from the mine to the test site in the loaded condition, then removed from the revenue train and operated through the test site several times, then re-joined to a revenue train where it would continue to the customer's dump facility. It was envisaged that it would complete 2-3 complete circuits of this route, only on the first route, however, would it be set out at the wayside measurement location for repeated tests.

The change of car type meant that the interface to the car was slightly different and thus some modification was necessary to the adapters.

All of the necessary modifications were made and a Resco representative travelled to Roanoke to oversee the installation of the trucks under the empty bottom-dump car. Because the prototype trucks had not been subject to fatigue testing to prove their life it was felt to be unduly risky to allow the trucks to be operated on the revenue train without supervision. It was agreed that a caboose would be attached to the car, which would be the last unit on the train, and that way its behaviour could be monitored by Norfolk Southern personnel who would ride in the caboose for the whole journey. A DO NOT HUMP order was placed on the car because the prototype trucks had not been designed to accommodate the forces inherent in a humping operation.

The test was begun and the empty car travelled from Roanoke to the mine in the empty condition, with the caboose connected and Norfolk Southern personnel on board. At every possible opportunity the trucks were examined and no untoward behaviour was identified. One factor that was quite evident was that the wheel flanges on the car with the Resco trucks were never touching the rails – unlike those on the standard trucks, because the machining marks on the flanges were still present after several hundred miles of operation.

The car was loaded and then brought to the Loudon, TN, test site and set out from the train and a Resco representative then travelled there to witness the tests through the wayside measuring location.

From the video views of the truck operation, available in the instrument car, it was clear that the steering motions were now occurring properly. No measurements were available in the caboose but the truck behaviour could be witnessed directly. The axle positions appeared to be as expected in all of the curves, and in both directions, and the truck appeared to have no difficulty centring itself properly after the curve. Immediately prior to entering the measurement crib in the middle of the tangent section between two back-to-back curves in the test section, however, it was observed that the truck would shift suddenly to one side, rather than continuing to track in the centre.

From standing at wayside whilst the test consist traversed the curves in the test section it was very evident that the steered trucks generated noticeably less noise than those in the rest of the consist. Test results from the wayside measurements were not available fully processed during the test period but preliminary indications were that the lateral forces in the curves were higher than expected – and similar to those on the standard trucks. More details of the test results appear in section 9. The car with the steered trucks was released to continue to the dumper, to be monitored by Norfolk-Southern personnel as before.

On its return journey from the dumper back to the mine, however, the car was inadvertently allowed to go through a hump yard, despite the DO NOT HUMP order, with the result that an axle was torn off the truck and ended up jammed under the car. Figure 9 shows the condition after this incident. Some damage was caused to the truck, of course.

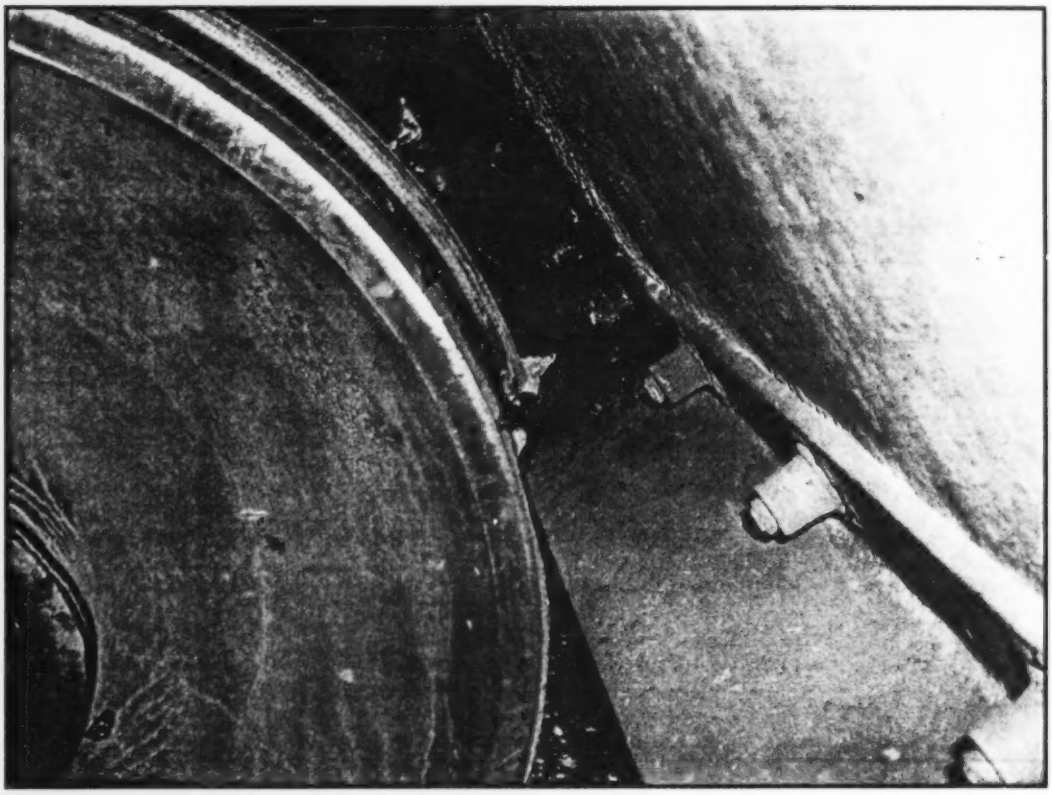

Figure 9. Wheel Jammed into Car Frame

This incident, and the subsequent damage to the truck, brought the test to an end. The rest of the test, however, would only have consisted of one or two more round trips from the mine to the dumper – no more multiple passes at the Loudon test site were planned – so very little extra data would have been generated.

7. Findings from the Mishap

When the trucks were taken out from under the car after the hump yard mishap the reason was discovered for higher wheel/rail lateral forces than had been expected. Figure 10 shows severe crushing and wear of the shear frame cross member within the truck.

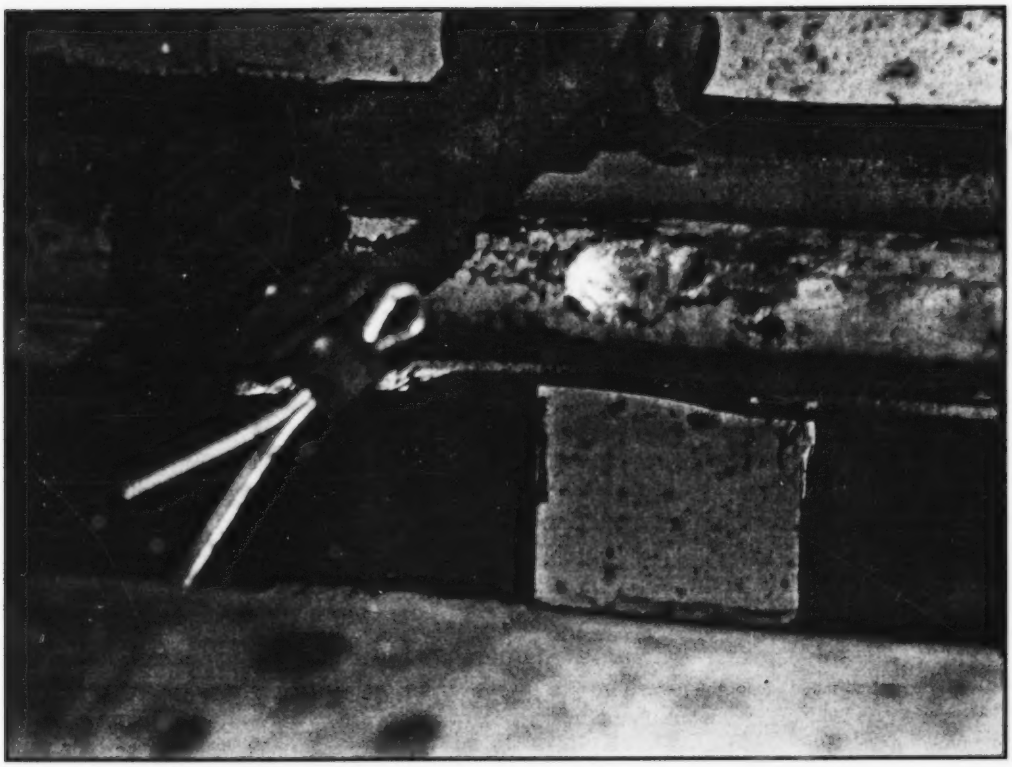

Figure 10. Shear Frame Damage

It was clear that the bracket on the carbody centresill, that attaches the top of the brake dead lever (just visible in the top of the picture) had been interfering severely with the cross member. This means that extremely high forces would be created in order to obtain the required truck rotation in a curve, and that the truck rotation would be constrained. The interference had not been noticed before because the car was assembled in the empty condition – when the bracket would be above the cross beam – and it was on tangent track. Only in the loaded condition, and in a curve, would the interference become evident.

This discovery uncovered the reason for the unexpected high lateral wheel/rail forces.

8. Discussion of Various Potential Truck Behaviour Scenarios

Before continuing to examine the test results from the steered truck it will be valuable to consider certain aspects of behaviour of various trucks in curves. The angle-of-attack of a wheelset relative to the track is defined as the angle made by the line of the axis of the wheelset with the line that is radial from the centre of the curve of the track to the centre of the wheelset. A positive angle-of-attack, for the purposes of this report, is defined as one in which the wheelset would tend to move towards the outer rail of the curve. The definition of the sign of the angle, therefore, is dependent upon the direction in which the

wheelset is travelling. The angles-of-attack between the wheelsets and the track that might be expected in various situations can be determined in the following manner.

Figure 11 shows a truck in which the axles are both exactly aligned with the curved track on which it is operating. In this case the lead axle angle-of-attack is zero and the trail axle angle-of-attack is zero and the difference of the angles-of-attack is also zero. In all of the Figures from 11 to 16 the direction of travel is assumed to be from right to left.

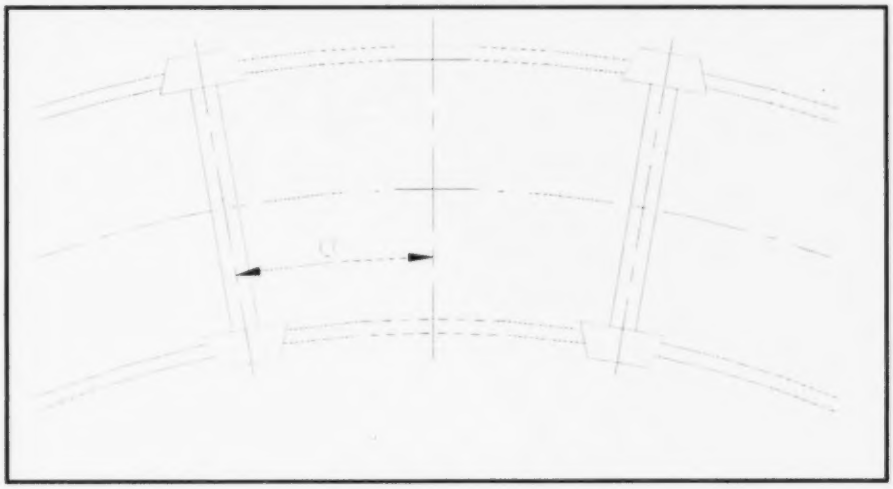

Figure 11. Perfect Alignment

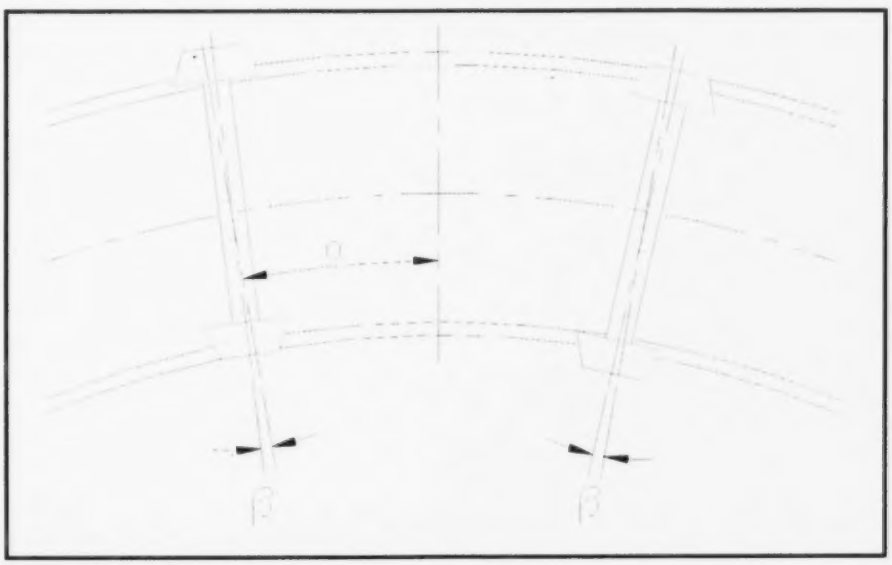

Figure 12. Perfect Steering – Truck Rotated or Sheared

Figure 12 shows the situation that would develop if the axles had the perfect steering angle between them but were both rotated away from perfect alignment with the curved

track by the same amount. This could occur if the truck was either over- or under-rotated relative to the track, or else if the truck frame became sheared – giving the same amount of misalignment rotation to both axles.

From Figure 12 we see that, in this situation, both the lead axle and trail axle angles-of-attack are equal to the angle of rotation (or shear) of the truck (β) but that the difference of the two angles-of-attack is still zero, just as in the perfectly aligned case.

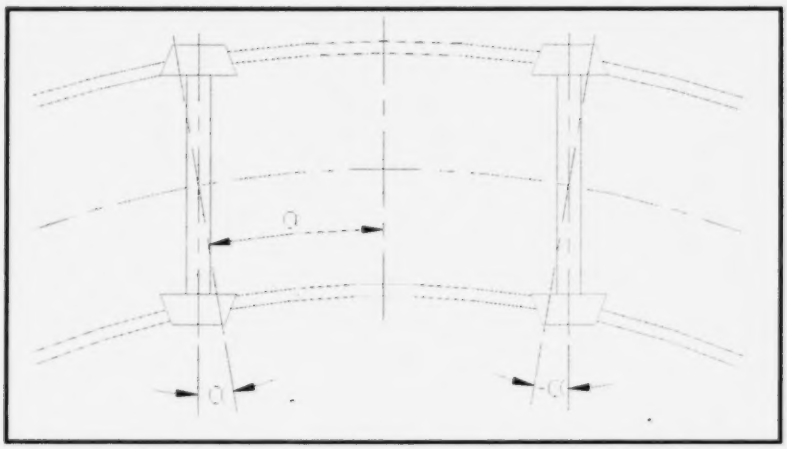

Figure 13. Rigid Truck, No Rotation

If the truck allows no steering action of the wheelsets whatsoever and is constrained from rotating relative to the curve (or from shearing) – as for a perfectly rigid truck with no flange clearance between the wheels and the rails, for instance, the situation would be as depicted in Figure 13. Here we see that the lead axle angle-of-attack is α, the trail axle angle-of-attack is $-\alpha$ and that the difference in the angles-of-attack is therefore 2α.

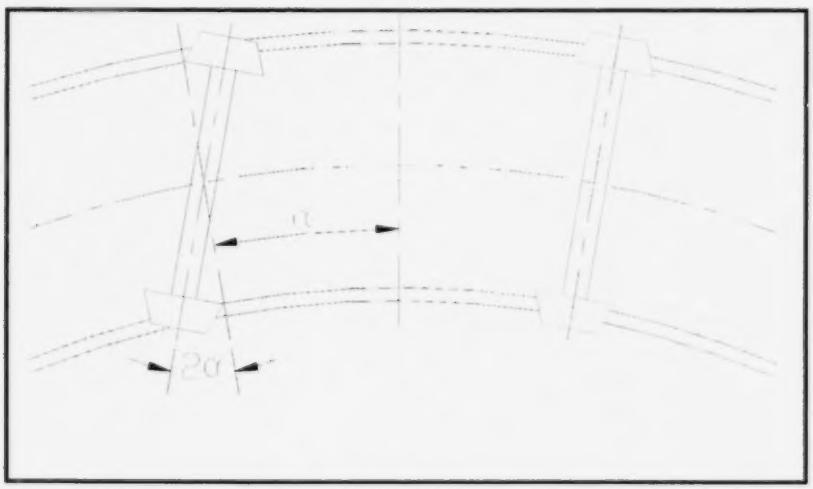

Figure 14. Parallel Axles – Sheared or Rotated to Align Trailing Axle

Figure 14 illustrates the condition when a truck maintains the axles parallel to one another but allows them to shear laterally relative to one another so as to rotate to a position where the trailing axle comes into perfect alignment with the track.

The same condition as is illustrated in Figure 14 can also occur when a rigid truck has sufficient flange clearance that it can rotate to align the trailing axle with the track. For either of these conditions we see that the lead axle angle-of-attack is 2α and so is the difference in the angles-of-attack.

In Figure 15 the condition is shown for a truck that has maintained the axles parallel to one another but has sheared to the point where the trailing axle has actually taken up a positive angle-of-attack as well as the leading one. It is most likely that this condition would occur due to excessive shearing of the frame (rather than over-rotation) because over-rotation would tend to be controlled by the lateral forces created at the trailing axle in the case of the rigid truck. Excessive shearing of the truck frame, to the point where the trailing axle generates a positive angle-of-attack, is known as warp collapse of the truck.

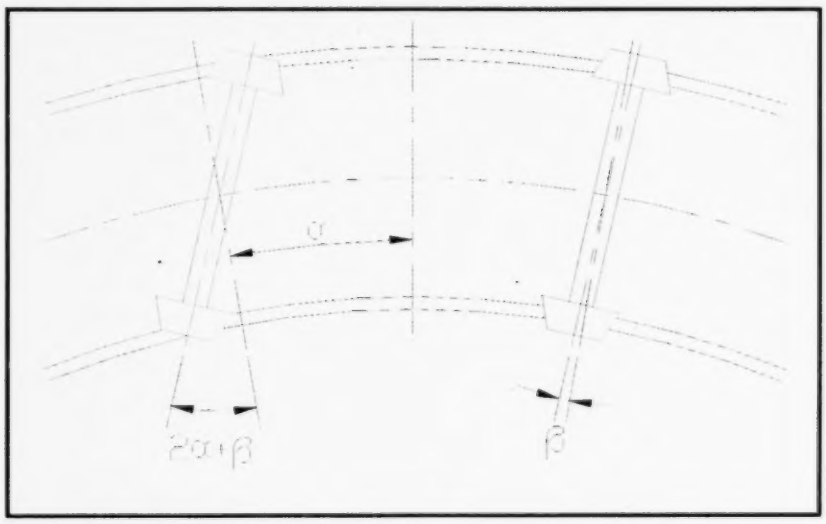

Figure 15. Excessively Sheared Truck Frame (Warp Collapse)

In this case the lead axle angle-of-attack is $2\alpha + \beta$ while the difference in the angles-of-attack remains at 2α.

The final case that we must examine is that where the truck has an ability for the axles to move away from the parallel configuration but the wheel/rail forces create an alignment that is in the opposite direction to that of the track curvature. This is illustrated in Figure 16 for a truck that is neither rotated nor sheared.

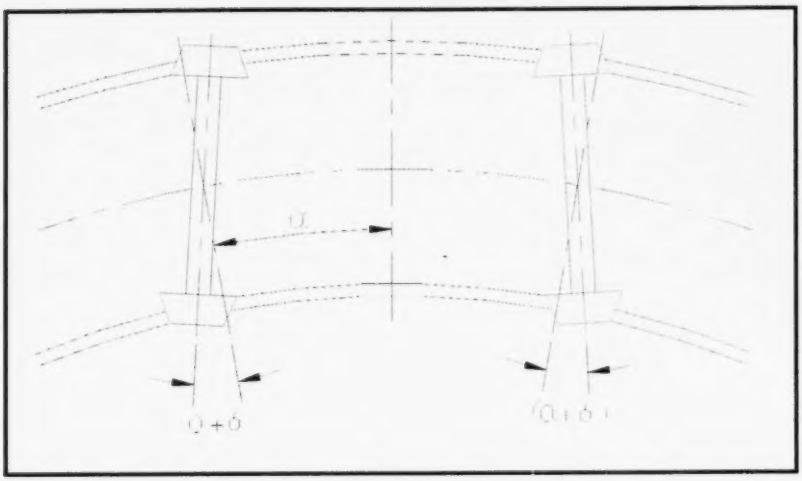

Figure 16. Anti-Steered Truck

Here we see that the difference in the angles-of-attack becomes $2(\alpha + \delta)$, this will be true regardless of the rotation or shearing of the truck, which will add the same quantity to both angles-of-attack. The lead axle angle-of-attack will be $(\alpha + \delta + \beta)$ where β is the amount of rotation or shear of the truck.

9. Test Results

The results from the Loudon tests were analyzed and are presented here. Measurements were available of the angles-of-attack of both axles of the truck in a curve. In order to determine how well the trucks were performing the results were examined in the following manner.

Figure 17 shows the results for the Resco truck from the Loudon tests. The results from both curves on the test site are combined on the one graph. It can be seen that these results all lie quite close to the vertical axis of the diagram – indicating that the difference in the angles-of-attack was small (so the steering was good) but that the leading axle angle-of-attack was finite (so the truck rotation or shear was not zero).

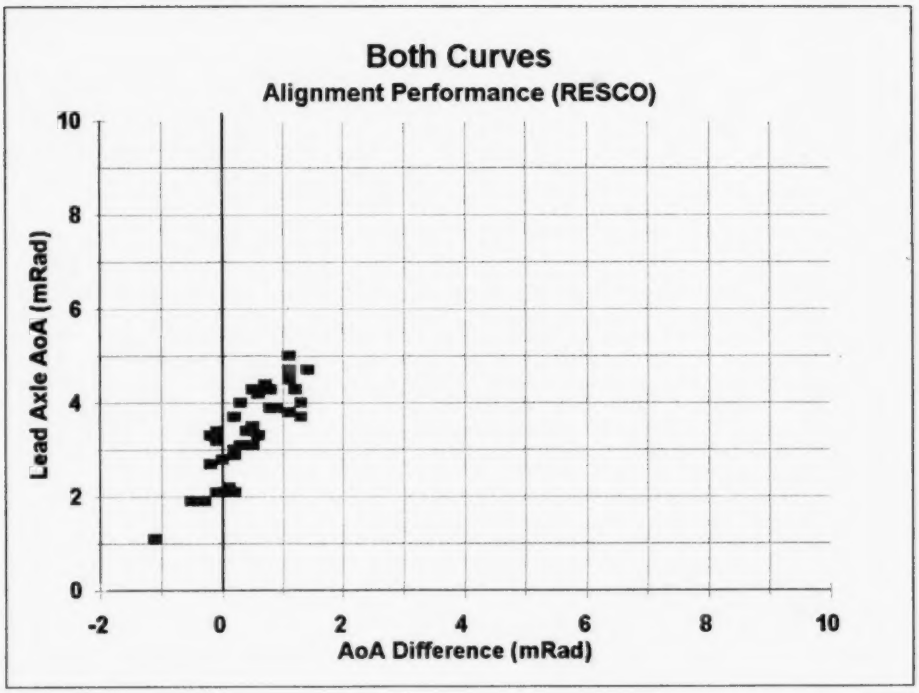

Figure 17. Resco Truck Results

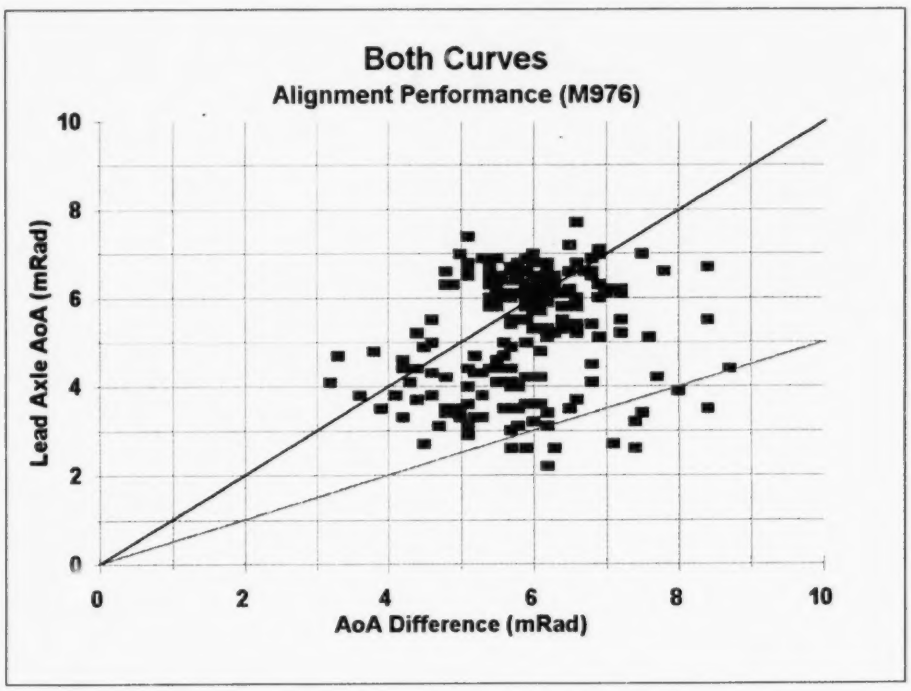

Figure 18. M976 Truck Results

The results for a set of "premium" M976 trucks operating through the same curves can be seen in Figure 18. Two extra lines are inscribed on this graph. The green line shows the locus of points that one would expect from a rigid truck that has not rotated to align the trailing axle. The blue line is the locus of points to be expected from a rigid truck that has rotated to align the trailing axle perfectly. These results show that the M976 trucks, on these curves, have largely rotated so as to align the trailing axles, although some results do lie in the region for non-alignment of the trailing axle.

In comparing the results from these tests it is important to keep in mind that the results for the Resco truck are from multiple passes of a single car through the test section whereas those from the M976 trucks are from a single pass of multiple trucks through the test section in one train. Data from other trucks passing through the test section on the same train as the Resco trucks were not available for comparison, for reasons of confidentiality.

A valuable way to look at these results is to examine two parameters – Theta, the angle of the data point from the origin, relative to the x-axis, and R, the radial distance of the data point from the origin. These parameters are illustrated in Figure 19. Theta is the angle whose tangent is the lead axle angle-of-attack divided by the difference in the angles-of-attack. R is the square root of the sum of the square of the lead axle angle-of-attack and the square of the difference in the angles-of-attack. As such, R is an indicator of the total alignment achieved. The closer R is to zero the better. For a perfectly steered truck Theta will be 90° and the R value will be zero.

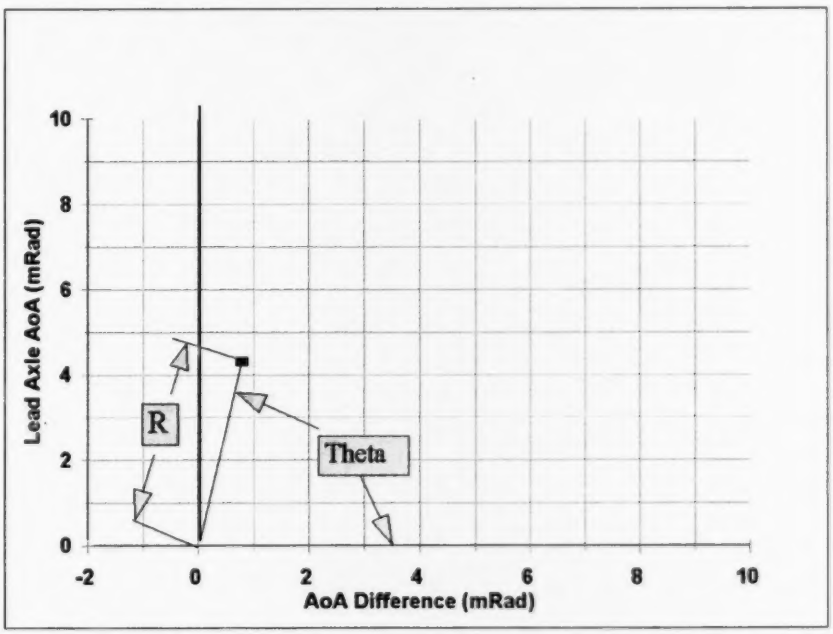

Figure 19. Definition of Theta and R

Going back to the conditions for various configurations of truck on a curve, as illustrated in Figures 11-16, it is easy to determine what the values of R and Theta will be expected to be for the different situations depicted.

From Figure 11 we saw that the lead axle angle-of-attack and the difference in the angles-of-attack will both be zero for the perfectly aligned truck. This means that the R value will be zero and the Theta value will be indeterminate. There is one caveat that must be mentioned here, however, and that is that real measurements will always include some error. If the actual value of both the lead axle angle-of-attack and the difference in the angles-of-attack is zero it can be anticipated that the errors, although small, will be randomly scattered around the zero. While this will mean that the R value will still be very small, the Theta value could become anything at all – the points being scattered randomly around the origin. For perfectly aligned steered trucks, therefore, the R value will provide a good indication of their performance but the Theta value could be an unreliable indicator, especially once R becomes very small.

From Figure 12 we saw that for a correctly steered truck having either some rotation or some shear deflection of the frame, the lead axle angle-of-attack would be equal to the rotation or shear angle, β, whereas the difference in the angles-of-attack would be zero. The R value would thus be β and the Theta value would be 90°.

From Figure 13 we saw that a rigid truck having no shear or rotation would produce a lead axle angle-of-attack of α (half the angle subtended at the centre of the track curvature by the distance apart of the axles) and a difference in the angles-of-attack of 2α. This gives a Theta value of $\tan^{-1}0.5$, or 26.6°, and a value for R of $\sqrt{5}.\alpha$.

From Figure 14 we saw that a truck with parallel axles, rotated or sheared so that the trailing axle is aligned with the track will produce a leading axle angle-of-attack of 2α and a difference in the angles-of-attack of 2α. This gives a Theta value of $\tan^{-1}1.0$, or 45°, and a value for R of $\sqrt{8}.\alpha$.

The case of a warp-collapsed truck, shown in Figure 15, produces a lead axle angle-of-attack of $2\alpha + \beta$ and a difference in the angles-of-attack of 2α. Theta, therefore, has a value of $\tan^{-1}(2\alpha + \beta)/2\alpha$, >45°, and a R has a value of $\sqrt{((2\alpha + \beta)^2 + (2\alpha)^2)} = >\sqrt{8}.\alpha$. A strongly over-rotated truck would also produce a similar result.

The last case, of the anti-steered truck, shown in Figure 16, produces a lead axle angle-of-attack of $(\alpha + \delta + \beta)$ and a difference in the angles-of-attack of $2(\alpha + \delta)$. Theta has a value of $\tan^{-1}(\alpha + \delta + \beta)/2(\alpha + \delta)$, which is likely to be somewhat greater than 26.6°, depending upon the value of β, and R has a value of $\sqrt{((2(\alpha + \delta)^2 + (\alpha + \delta + \beta)^2)} = \sqrt{(5\alpha^2 + 5\delta^2 + \beta^2 + 10\alpha\delta + 2\alpha\beta + 2\delta\beta)}$. This is the only case in which the difference in the angles-of-attack exceeds 2α and the expression for R shows that this value can be expected to become very high in these circumstances, depending upon the values of β and δ.

The curves in the Loudon test section were both close to 5.3°, this means that the value for α in a truck with a 70" wheelbase is 2.69 mRad. The difference in angles-of-attack for a truck with axles that remain parallel should therefore be 5.39 mRad. A truck which has effective steering will produce values significantly lower than this and a truck which is anti-steering will produce values that are higher. Examination of figures 17 and 18 shows that the RESCO truck has effective steering, whereas the M976 truck has values which lie between the non-steered and the significantly anti-steered conditions.

The R values that would be expected in these curves would be 6.0 mRad for a rigid truck that has no shearing or rotation and 7.6 mRad for a parallel axle truck that has the trailing axle fully aligned (either through shearing or rotation)

Figure 20 compares the distribution of the results for Theta for the Resco trucks and the M976 trucks passing through the Loudon test section. Some data from standard three-piece trucks is also shown in that figure. The data points for each truck style were examined and the normal distribution for the data set shown on a graph of probability vs the Theta value.

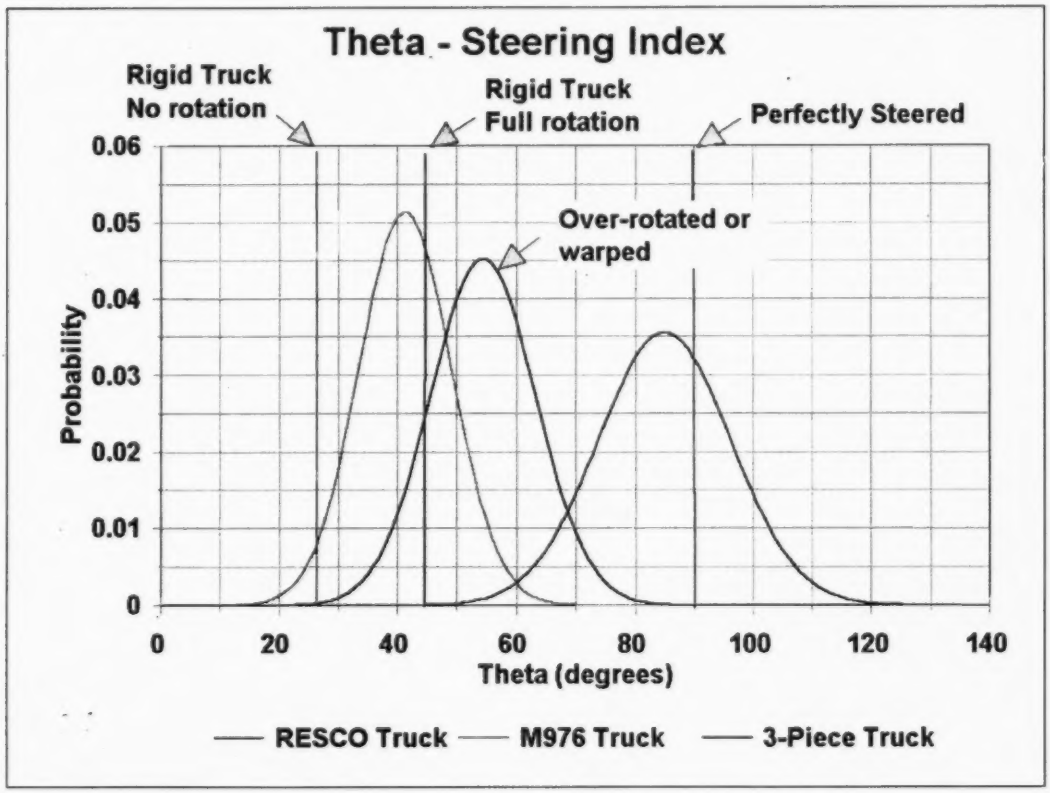

Figure 20. Theta Values

The distribution depicted by the red line in the figure is that for the Resco truck. The green line is for the M976 truck and the blue line is for the three-piece truck, passing

through the same site. It is clear that only the Resco truck shows behaviour close to that of a truck with significant steering. It is interesting that the three-piece truck shows Theta values that are closer to those for the steered condition than the M976 truck. This has to be examined in conjunction with the R values, however. We saw that the addition of shearing deflections in a truck can lead to higher values of Theta, but this does not necessarily indicate better steering.

Figure 21 shows a similar plot of the R value distributions for the various types of truck. The M976 trucks behave close to what one would expect from a well-performing but non-steered truck, but many are probably anti-steered – that being the most likely way to produce an R value greater than 7.6.

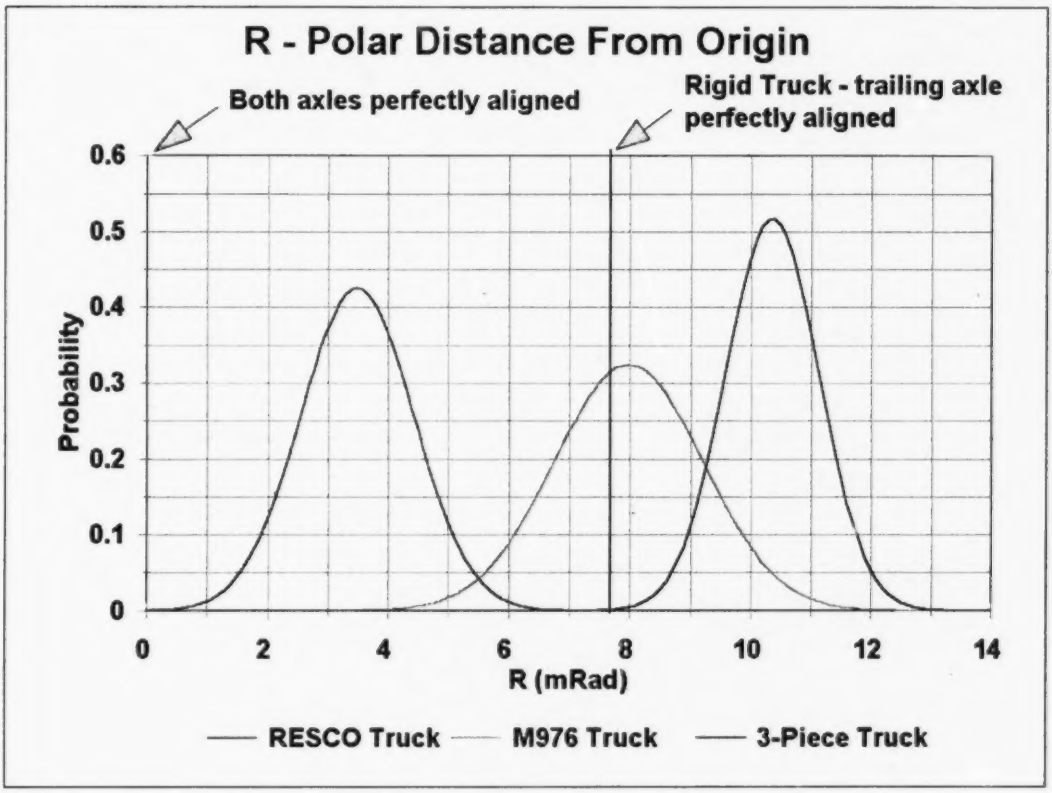

Figure 21. R Values

The three-piece truck is substantially worse, confirming that these trucks probably had significant anti-steering, and the Resco truck is behaving very much better than either of the other trucks. It should be noted that, because the R value is derived from the root of the sum of squares, it is always a positive value. For that reason the steered truck that is well-behaved still will not have the mean of its distribution on the zero axis. The mean value for R for the Resco truck, however, at about 3.5 mRad (0.2°), is a very small value – unmatched by the other trucks.

10. Wheel/Rail Conditions

Profiles were taken of the wheels on the test car and the rails at the test site, using Miniprof© instruments. These instruments produce high resolution digital files describing the geometry of the profiles, which can then be converted into drawing formats and superimposed to show the interaction of the wheels against the rails. Figure 22 shows the condition at the high rail of the East curve, in the centre of the measurement location, and Figure 23 shows the corresponding low rail condition. In both cases it is assumed that the wheelset has moved into flange contact with the high rail.

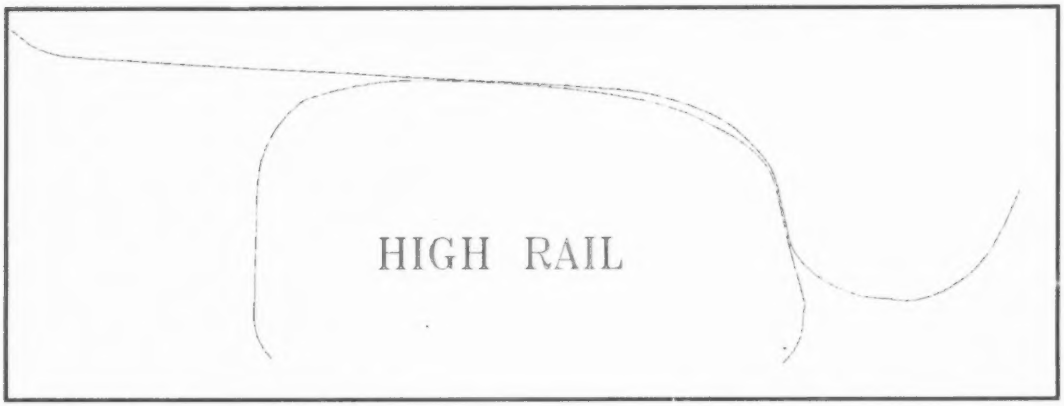

Figure 22. High Rail – East Curve

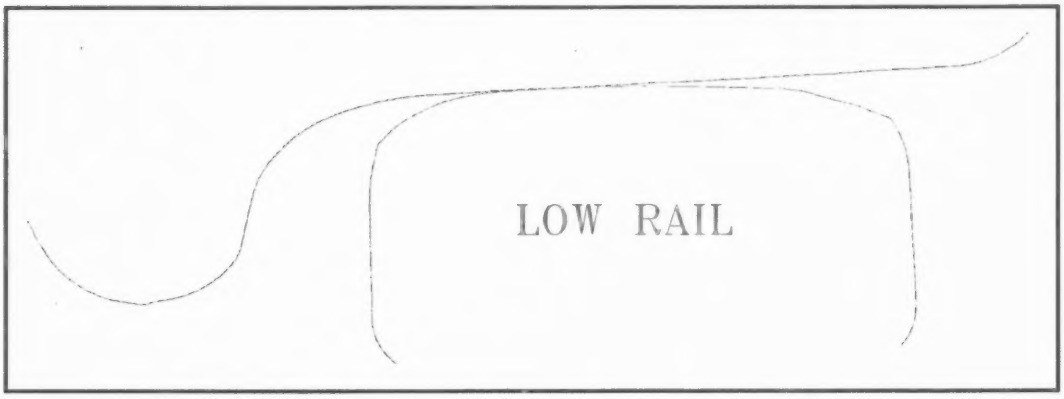

Figure 23. Low Rail – East Curve

From these figures it is clear that the tread contact point on the high side wheel is far from the flange, almost at the taping line. On the low side wheel the contact is similarly very close to the taping line of the wheel. It is evident from these contact conditions that the rails in this curve have been maintained to ensure contact at the centre of the high rail and towards the gauge side on the low rail. This is an undesirable condition that creates anti-steering moments. For the condition where the wheelset is positioned closer to the

low rail, as might occur on the trailing axle of a non-steered truck, the contact conditions and the anti-steering moments will become even worse.

Figures 24 and 25 show the contact conditions for the centre of the measurement location in the West curve.

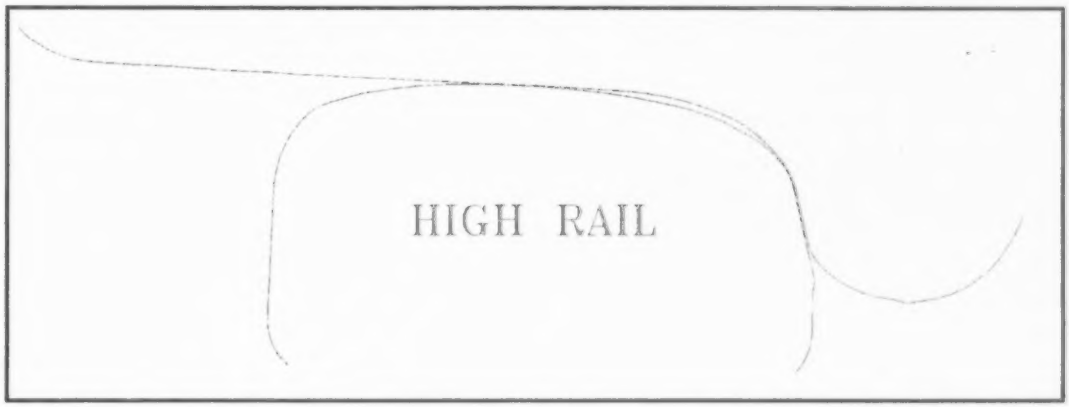

Figure 24. High Rail – West Curve

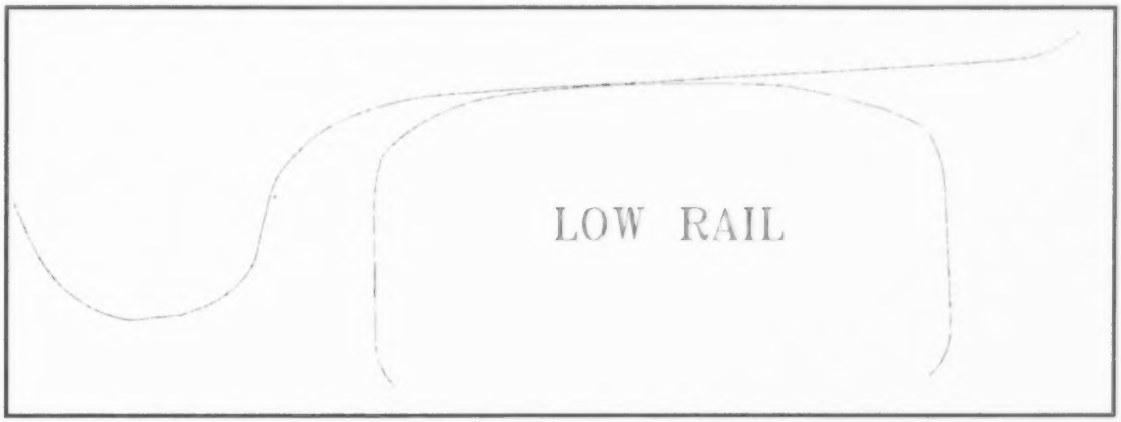

Figure 25. Low Rail – West Curve

It is clear from these two figures that the same condition has been created on the West curve of the test site as was seen on the East curve. The wheel/rail contact conditions for these rails, with AAR1B wheel profiles, will create significant anti-steering moments on the wheelsets.

Significant corrective grinding is needed in both of these curves to bring the contact conditions to a desirable state. The conditions existing provide an explanation for the observations from the test data. The rotation of the Resco truck, creating a small but finite value of R in the results, is almost certainly due to the moments that were created on both axles – turning the truck so as to produce a small but positive angle-of-attack at

both axles. The significant anti-steering seen in much of the data from the non-steered trucks is also due to this effect. It is to be expected that the anti-steering condition will exist on very sharp curves but ones such as these (~5°) should not produce that phenomenon.

11. Conclusions

Before turning our attention to the conclusions to be made concerning the Resco Steered Frame Truck, which was the prime purpose of the tests reported on here, some observations can be made with respect to the existing alternate trucks whose performance was also observed in the tests.

It is sometimes claimed that the 'premium' trucks have a self-steering capability that provides lower wheel and rail wear as well as reduced fuel consumption when compared with the standard three-piece truck. Examination of the results contained herein show that this is not the case – in fact the premium trucks showed less self-steering capability (worse values of 'theta') than the three-piece trucks. The premium trucks did show results closer to those of a rigid truck – which is clearly the major improvement provided by the design modifications associated with the premium trucks (wider wedges and bearing adapters that are locked to the side frame pedestals).

The attractive results obtained from testing under controlled conditions at the Pueblo test track have been seen to be still true in less than ideal conditions in the real world. The Resco Steered Frame Freight Car Truck has proven, in a revenue service application, that it achieves performance levels that other freight car trucks do not – not even the higher-priced 'premium' trucks currently available.

The conditions under which the performance levels were achieved were less than optimum for the truck. The rail condition was poor through the test section – poorer than would be expected to be found in most railroad curves in North America. There was interference in the truck, causing it to rotate less in the curve than it should have been free to attain. It is to be expected that the performance levels in both Theta and R values will be even further improved in a production model that eliminates the unforeseen and undesirable interference.

There are potential interference problems between the steered truck and body mounted brake systems that need to be carefully examined in a production design.

It is felt that the combined results of these tests and all of the work that has previously been reported show that the Resco steered frame truck is now ready to proceed to the next stage of development – the design and demonstration of a production version. A production version of the truck will, of course, eliminate all of the geometrical issues identified with the prototypes, and will be subjected to the full series of AAR approval tests and demonstrations. To this end, since the conclusion of these tests, Resco has been actively seeking a partner with whom to proceed in that direction.